UNCLASSIFIED

AD NUMBER
AD103229
CLASSIFICATION CHANGES
TO: **UNCLASSIFIED**
FROM: **CONFIDENTIAL**
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 06 MAY 1956. Other requests shall be referred to Office of Naval Research, Arlington, VA 22203.**
AUTHORITY
ONR ltr 28 Jul 1977 ; ONR ltr 28 Jul 1977

THIS PAGE IS UNCLASSIFIED

[redacted]

AD 103229

Armed Services Technical Information Agency

Reproduced by

DOCUMENT SERVICE CENTER

KNOTT BUILDING, DAYTON, 2, OHIO

[redacted]

103229

[redacted]

FC

ENGINEERING REPORT NO. 114.7

AERODYNAMIC ANALYSIS REPORT
TRANSPORT PROPELLOPLANE STUDY

Contract Nonr 1657(00)

[redacted]

114.7

AUG 2 1956

CGAA 46991 1-4/57

NOTICE: THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 and 794. THE TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

CONFIDENTIAL

HILLER HELICOPTERS

PALO ALTO, CALIFORNIA

ENGINEERING REPORT

REPORT NO. 114.7

MODEL NO. 1048

TITLE AERODYNAMIC ANALYSIS REPORT FOR TRANSPORT PROPELLOPLANE STUDY - CONTRACT NONR 1657 (00)

NO. OF PAGES 41

DATE May 4, 1956

BY W. Young

ASSISTED BY M. B. Houck

CHECKED R. Herda
R. Herda

APPROVED R. M. Carlson
R. Carlson

APPROVED W. Wiesner for R. Wagner

This document has been reviewed in accordance with OPNAV ... The security classification ... is correct.

Date 8/10/56 By C. Fortune

Chief of Naval Research (Code 461)

REVISIONS

DATE	PAGE NUMBER

CONFIDENTIAL

FORM 80.030 A

56AA 46991

INDEX

CONFIDENTIAL

SYMBOLS

AF - Propeller Activity Factor

AR - Geometric Aspect Ratio of Aircraft Wing $= \frac{b^2}{S}$

B - Number of Propeller Blades

b - Wing Span - Feet.

D - Drag, Pounds

D_P - Propeller Diameter, Feet.

e - Oswalds Equivalent Aircraft Span Efficiency Factor

F - Fuel, Pounds

f - Equivalent Parasite Drag Area, ft^2

H - Altitude, Feet

K - Constant

N - Number of Propellers

NRP - Normal Rated Power, Shaft Horsepower

Q_T - Thrust Coefficient

R - Range, Nautical Miles

R/C - Rate of Climb, FPM

R/D - Rate of Descent, ft. per minute.

R_F - Fuel Weight/Gross Weight

S - Wing Area - Square Feet

SHP - Shaft Horsepower

T_C - Torque Coefficient

THP_a - Thrust Horsepower Available, $= T \times V$

CONFIDENTIAL

CONFIDENTIAL

SYMBOLS

THP_r - Thrust Horsepower Required

V - Velocity, Nautical Miles per Hour, True Air Speed.

v - Velocity, FPS

V_T - Propeller Tip Speed - FPS

w - Disk Loading, lbs/sq.ft. $= \dfrac{W_G}{\dfrac{N \pi Dp^2}{4}}$

W_G - Airplane Weight, Pounds

W_H - Thrust Loading, lbs/sq.ft. $= \dfrac{\text{Sea Level Static Thrust}}{\text{Propeller Disk Area}}$

η - Propeller Efficiency

ρ - Mass Density of Air, Slugs/ft^3

SUBSCRIPTS

A - Refers to Engine A

a - Available

B - Refers to Engine B

c - Climb

d - Descent

e - Engine

F - Fuel

CONFIDENTIAL

SUBSCRIPTS

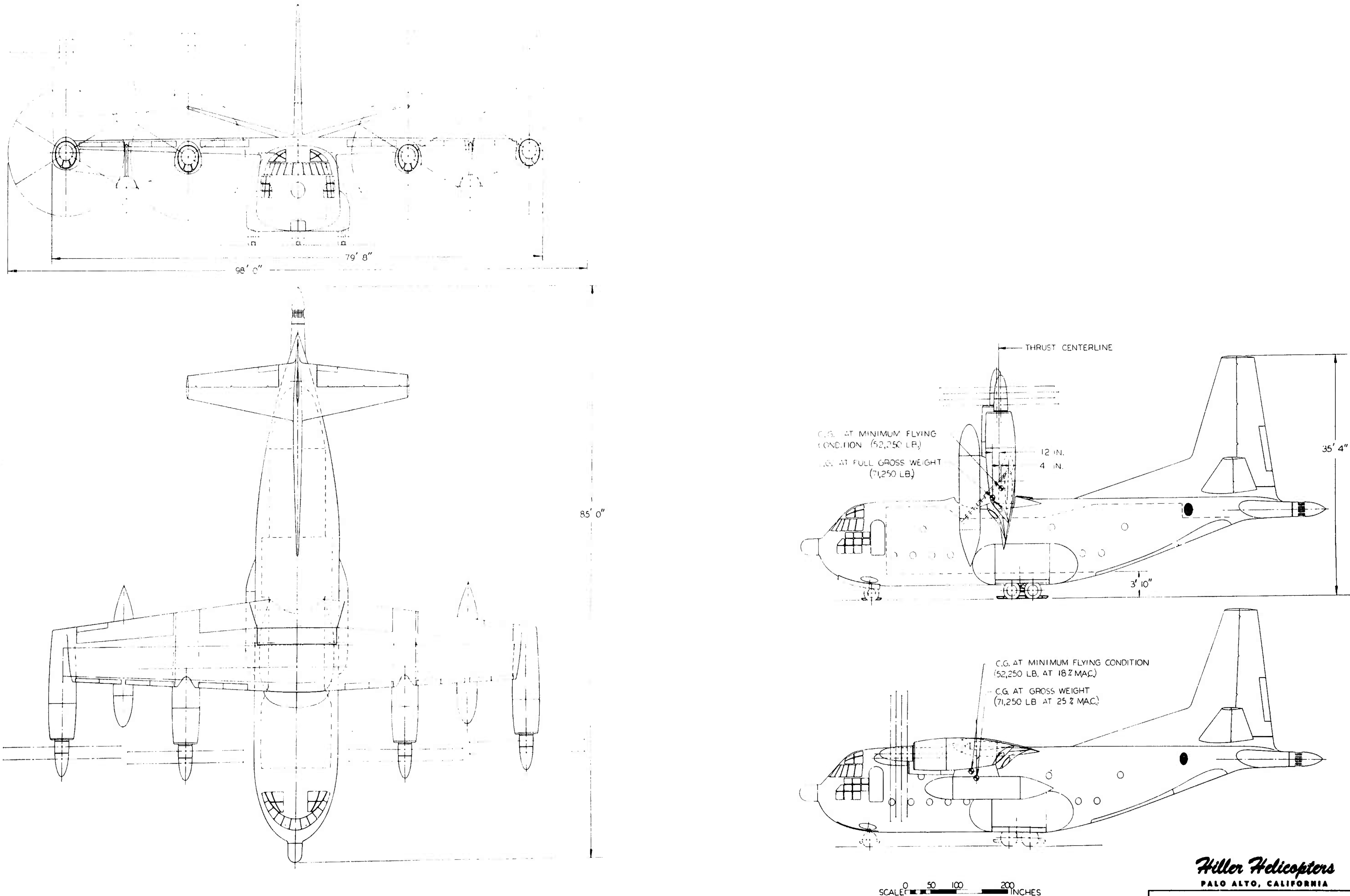
G	–	Gross
I	–	Inboard
O	–	Standard Sea Level or Outboard
P	–	Propeller or Propeller Shaft
R	–	Required
T	–	Tip
8	–	8 Engine or Total

1.0 SUMMARY

This report provides an aerodynamic analysis and outlines methods used in obtaining the aerodynamic "R_F" for the solution of the optimum transport propelloplane under contract Nonr 1657 (00). The combination of aerodynamics and weights "R_F" (Reference 2) by the method described in Reference 1 yielded the optimum aircraft.

Minimum gross weight was considered to be the criterion for optimum selection. A three view drawing of the optimum aircraft is provided on the following page.

CONFIDENTIAL



Hiller Helicopters
PALO ALTO, CALIFORNIA

GENERAL ARRANGEMENT			
SCALE NOTED	DRAWN HOBART APP'D [illegible]	DATE 4-4-56 DATE [illegible]	DRAWING NO. 1048A-001

CONFIDENTIAL

CONFIDENTIAL

2.0 GENERAL CONSIDERATIONS AND ASSUMPTIONS

2.1 Engine Characteristics

Generalized shaft turbine engine characteristics according to Reference 3 for the year 1965 were used. Specific fuel consumption versus % NRP curves are repeated in Figure 2 for easy reference.

The contribution of turbine jet thrust to forward flight propulsion was not considered, since its effect was small at the flight speeds encountered and insignificant on a comparative basis as affecting the optimum selection.

2.2 Gear Box "Derating"

As a result of the gear boxes being derated, the power output per two engine combination is limited to 75 percent of sea level NRP.

2.3 Drag

The equivalent parasite drag area, f, was computed to be 41.2 ft^2 in cruise configuration with external fuel tanks. This value was assumed constant for the matrix of possible aircraft considered.

2.4 Power Required

Airplane thrust horsepower required is defined by the following expression:

$$THP_r = \frac{\frac{\rho}{\rho_o} V^3 f}{96100} + \frac{W_G \left(\frac{W_G}{S}\right)}{3.47 \, AReV \frac{\rho}{\rho_o}}$$

$$\text{Let } K = \frac{W_G \left(\frac{W_G}{S}\right)}{3.47 \, ARe} \qquad (1)$$

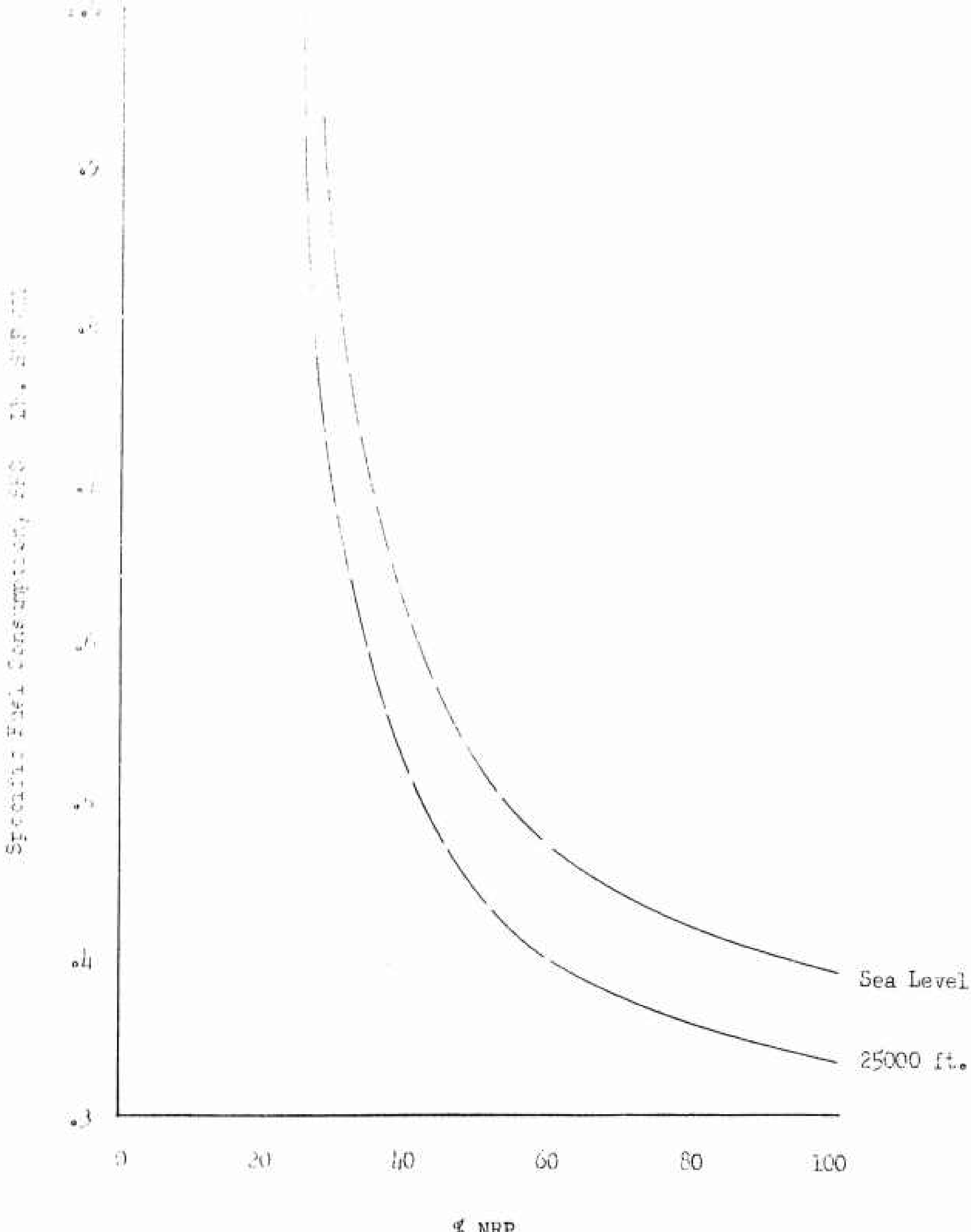
$$f = 41.2 \text{ (see 2.3), then}$$

$$THP_r = \frac{\frac{\rho}{\rho_o} V^3}{2330} + \frac{K}{\frac{\rho}{\rho_o} V} \qquad (2)$$

CONFIDENTIAL

2.4 Power Required (Continued)

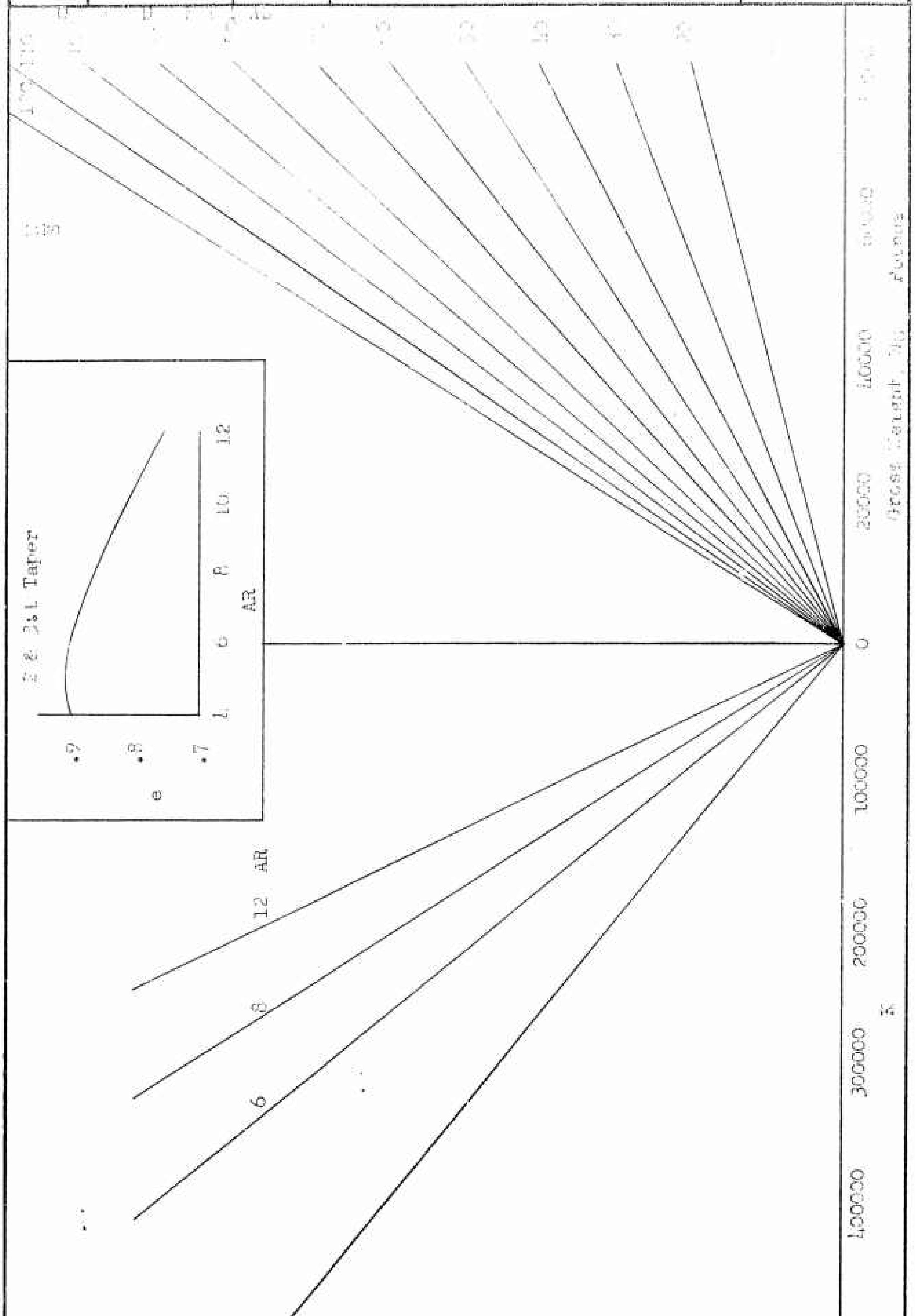
Equations (1) and (2) are plotted on the following pages (Figures 3, 4, and 5) permitting the solution of THP_r for selected values of ρ/ρ_0, V, W_G, W_G/S, and AR. Figure 6 shows the assumed variation of e with AR, being reproduced from Reference 4.



CONFIDENTIAL

60-028

PREPARED	NAME	DATE	HILLER HELICOPTERS	PAGE
CHECKED			TITLE	MODEL
APPROVED				REPORT NO

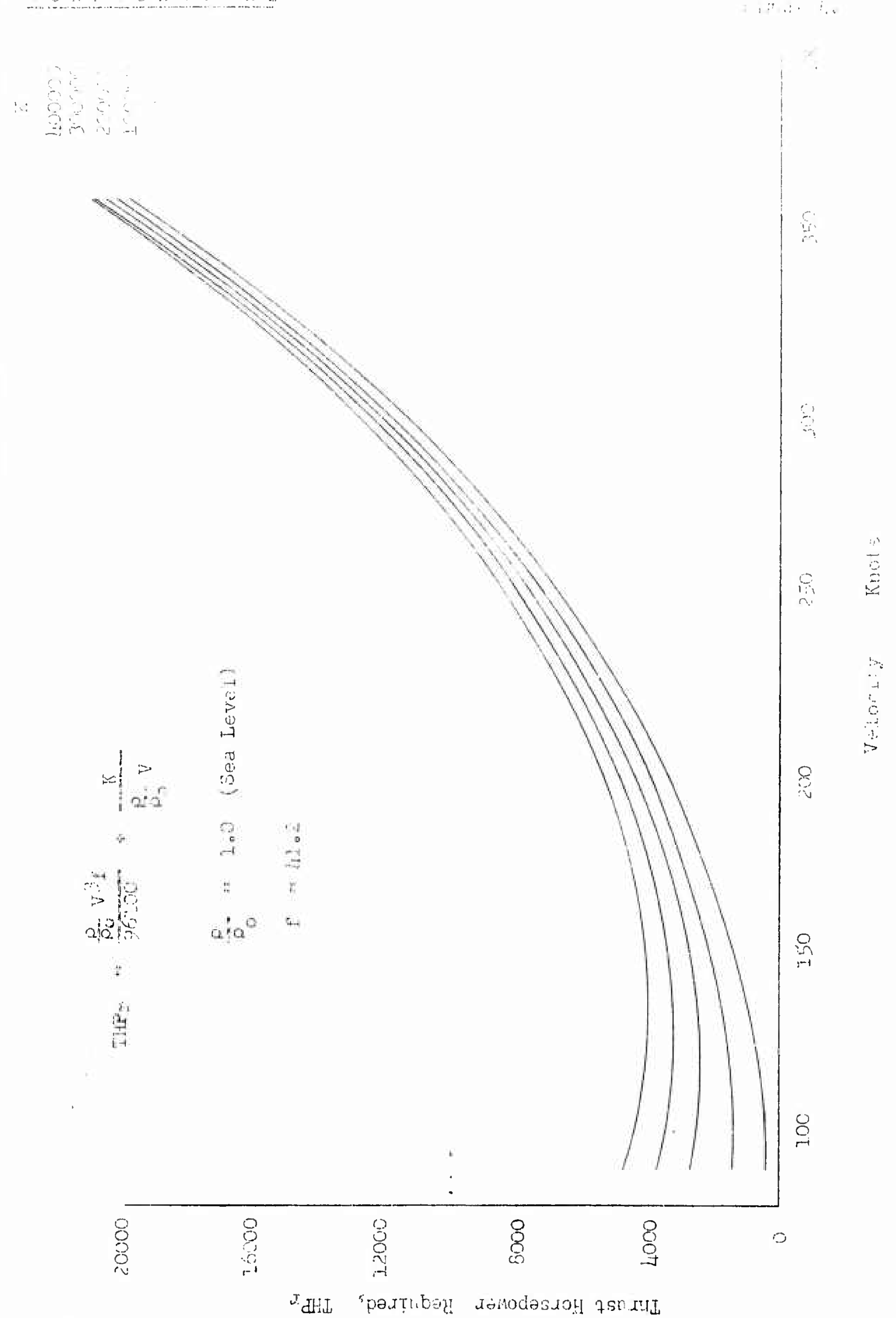


CONFIDENTIAL

Figure 3.

PREPARED			HILLER HELICOPTERS	PAGE
CHECKED				MODEL
APPROVED				REPORT NO

CONFIDENTIAL

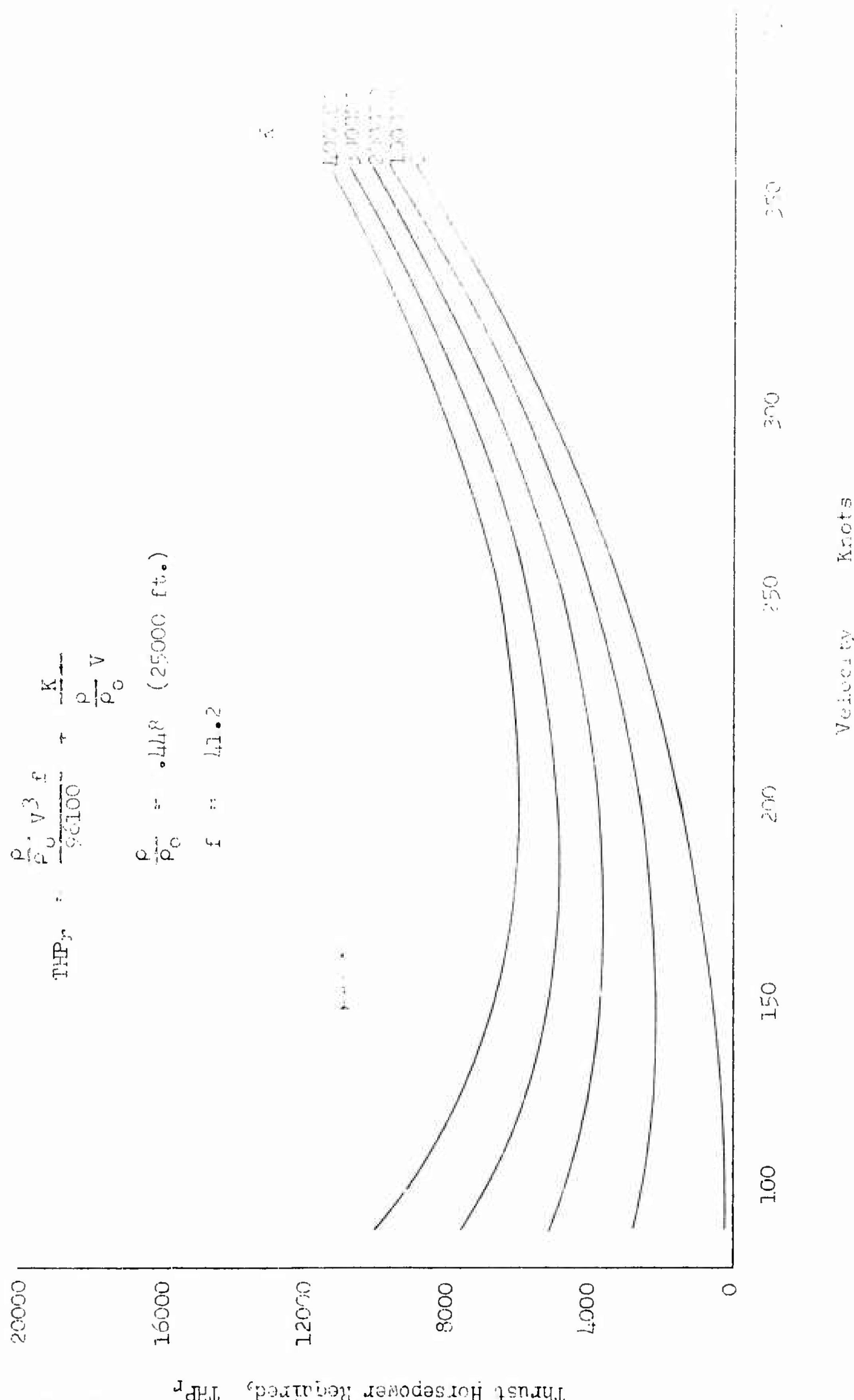


60-028 CONFIDENTIAL

PREPARED	NAME	DATE	HILLER HELICOPTERS	PAGE
CHECKED			TITLE	MODEL
APPROVED				REPORT NO

CONFIDENTIAL

Figure



CONFIDENTIAL

2.5 Power Available

In order to describe the available thrust horsepower characteristics of an aircraft, the following must be known.

1. Installed Horsepower
2. Propeller Diameter.
3. BAF
4. Tip Speed
5. Altitude
6. Type of Propeller, i.e. Single or Dual Rotation
7. Propeller Characteristics, i.e. Variation of Propeller Efficiency with Forward Speed.

Items 1-3 were obtained on the basis of the 6000' 95°F hover ceiling requirement and minimum power package weight. A complete discussion of this is contained in Reference 2.

Items 4-5 Variables.

Item 6 Dual rotating propellers were used.

Item 7 Propeller characteristics were obtained from Reference 5.

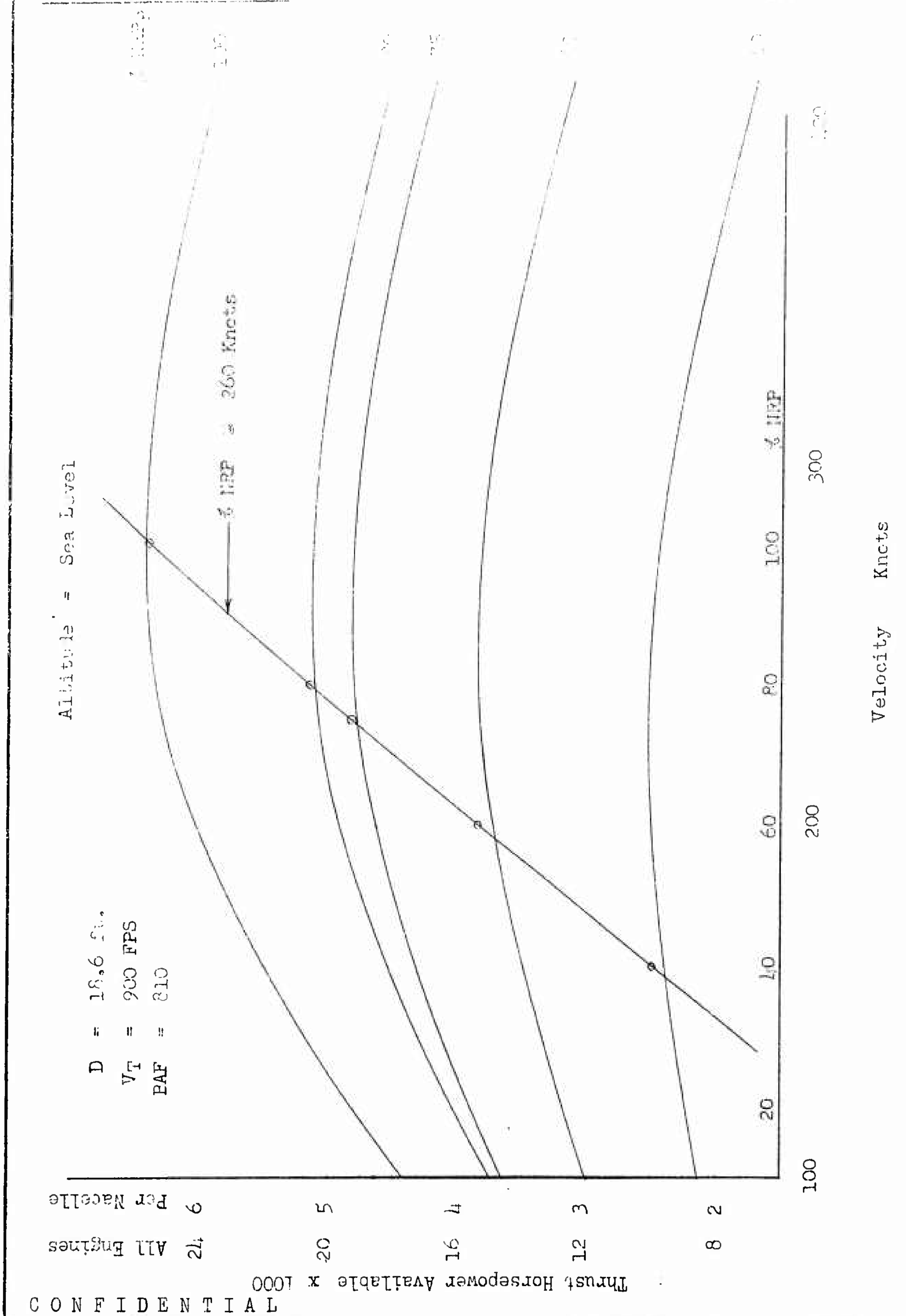
For purposes of illustration, Figures 7 through 10 show the variation of propeller efficiency and thrust horsepower with forward flight velocity at various percentages of shaft horsepower for the optimum aircraft (Figure 1).

CONFIDENTIAL

PREPARED	NAME	DATE	HILLER HELICOPTERS	PAGE
CHECKED			TITLE	MODEL
APPROVED				REPORT NO

CONFIDENTIAL

Figure 7.

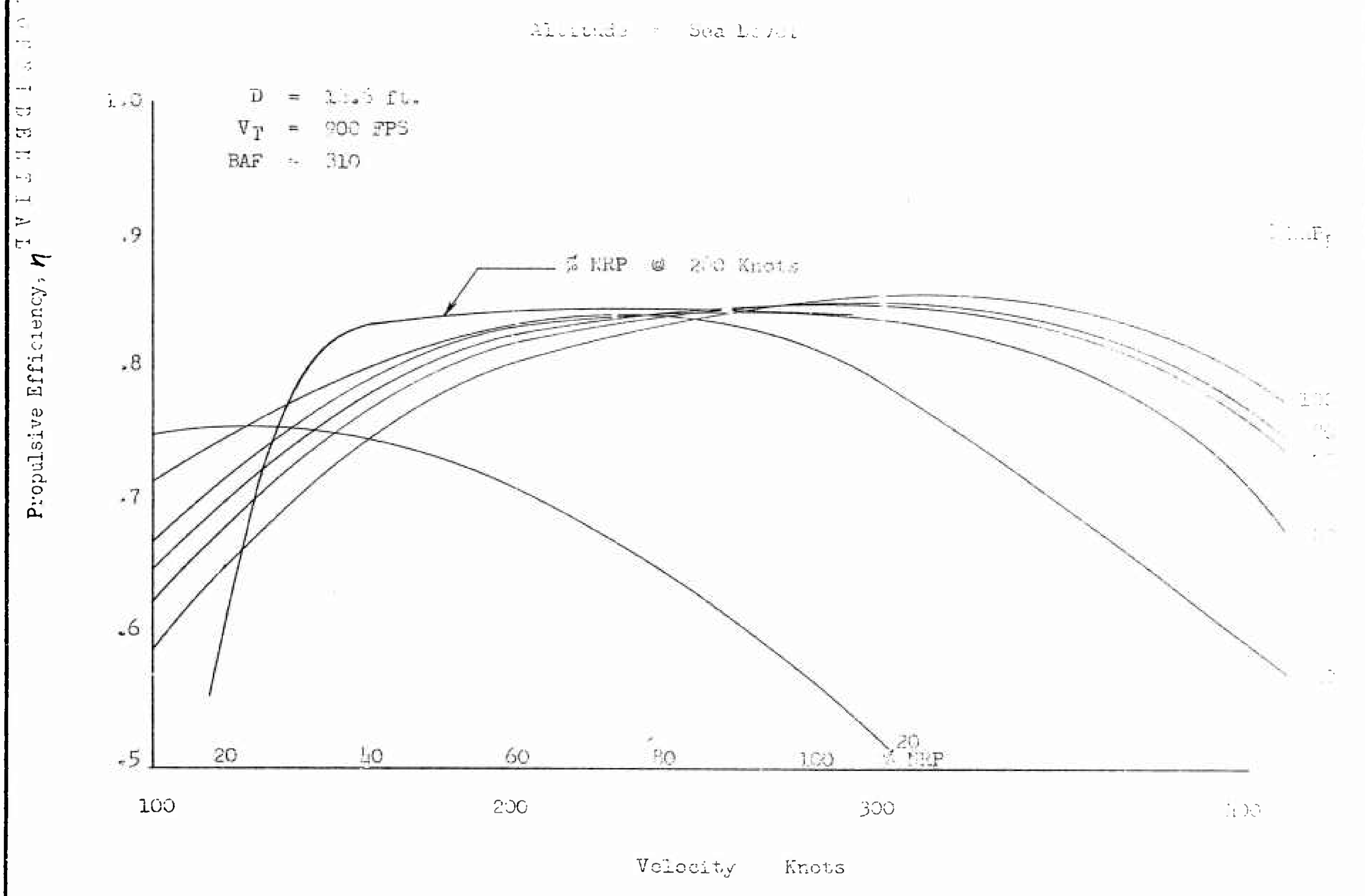


CONFIDENTIAL

60-028

PREPARED	NAME	DATE	HILLER HELICOPTERS	PAGE
CHECKED			TITLE	MODEL
APPROVED				REPORT NO

Figure 6.



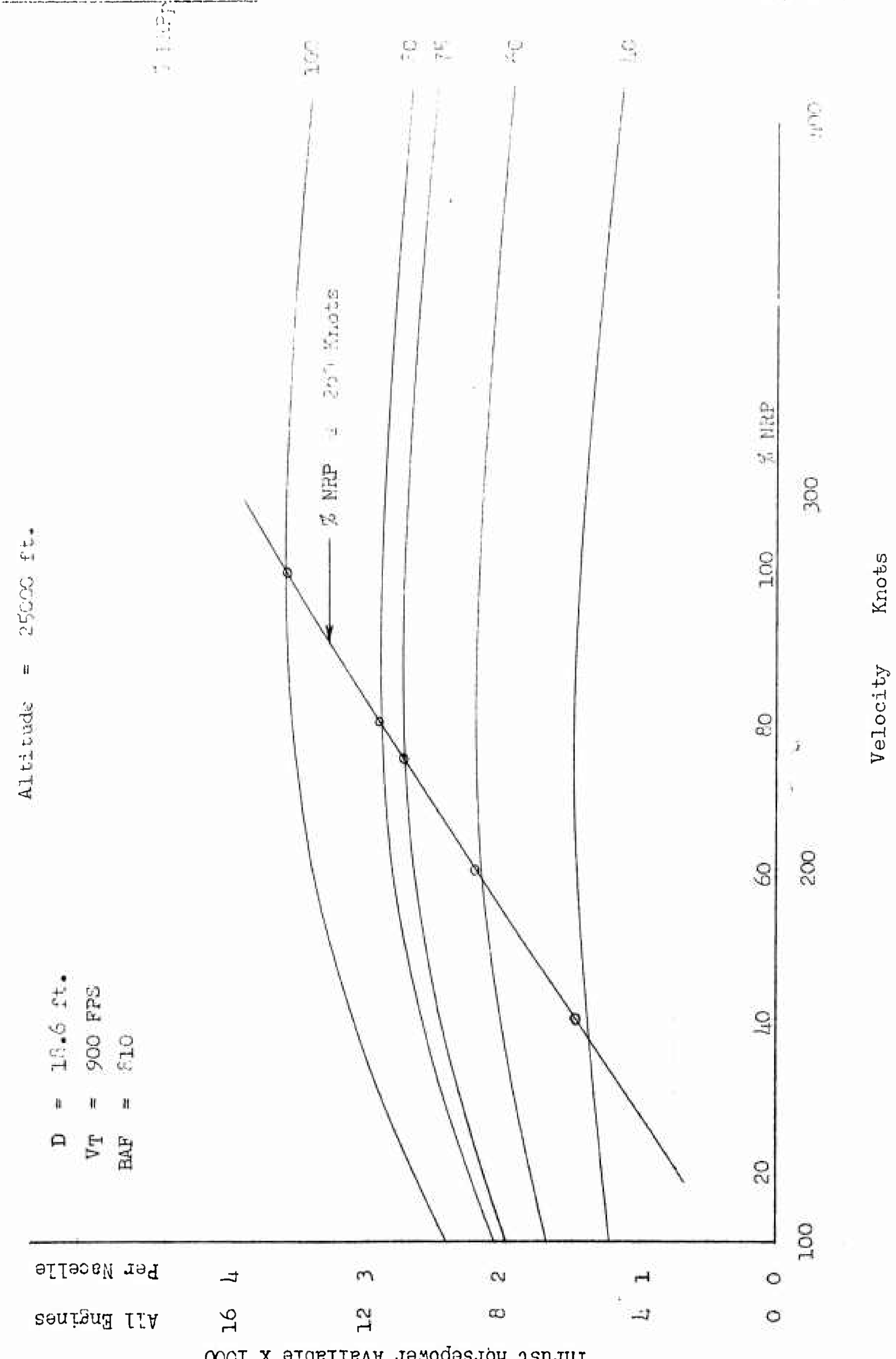
CONFIDENTIAL

60-028

PREPARED	NAME	DATE	HILLER HELICOPTERS	PAGE
CHECKED			TITLE	MODEL
APPROVED				REPORT NO

CONFIDENTIAL

Figure 9

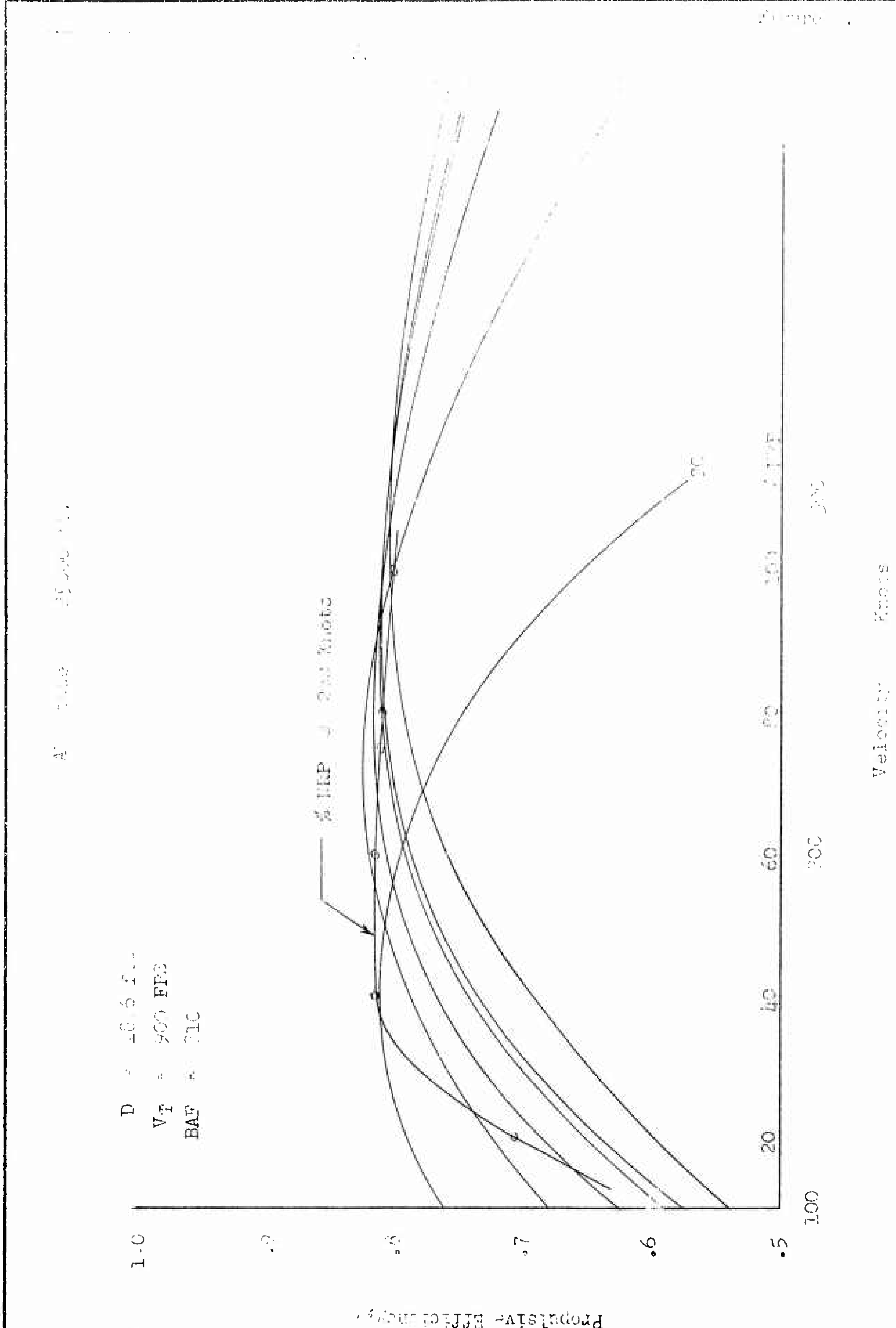


CONFIDENTIAL

60-028

HILLER HELICOPTERS

PREPARED			HILLER HELICOPTERS	PAGE
CHECKED			TITLE	MODEL
APPROVED				REPORT NO.



60-028

2.6 Engine Operation

The transport propelloplane under consideration provides for a total of 8 engines and 4 nacelles (2 engines per nacelle). When cruising at less than full power, a number of possible operating combinations exist. It is the object of this section to determine a schedule of engine operation which will require the least fuel and still be consistent with safe operating procedures. The assumption is made that the applied thrust must at all times be symmetrical; therefore, engines must be shut down in pairs and propellers must be feathered in pairs.

2.6.1 Engine Operation Within a Single Nacelle

Let the 2 engines be denoted A and B, then

$$\frac{FUEL}{HR} = SFC_{NET}\, SHP_P = SFC_A\, SHP_A + SFC_B\, SHP_B$$

$$\frac{FUEL}{SHP_P - HR} = SFC_{NET} = SFC_A \frac{SHP_A}{SHP_P} + SFC_B \frac{SHP_B}{SHP_P}$$

$$SHP_A + SHP_B = SHP_P$$

let $R_A = \dfrac{SHP_A}{SHP_P}$ $\quad R_B = \dfrac{SHP_B}{SHP_P}$ then, $R_A + R_B = 1.0$

$$\text{Also,} \quad \tfrac{1}{2}(\%\ NRP_A) + \tfrac{1}{2}(\%\ NRP_B) = \%\ NRP_P \qquad (3)$$

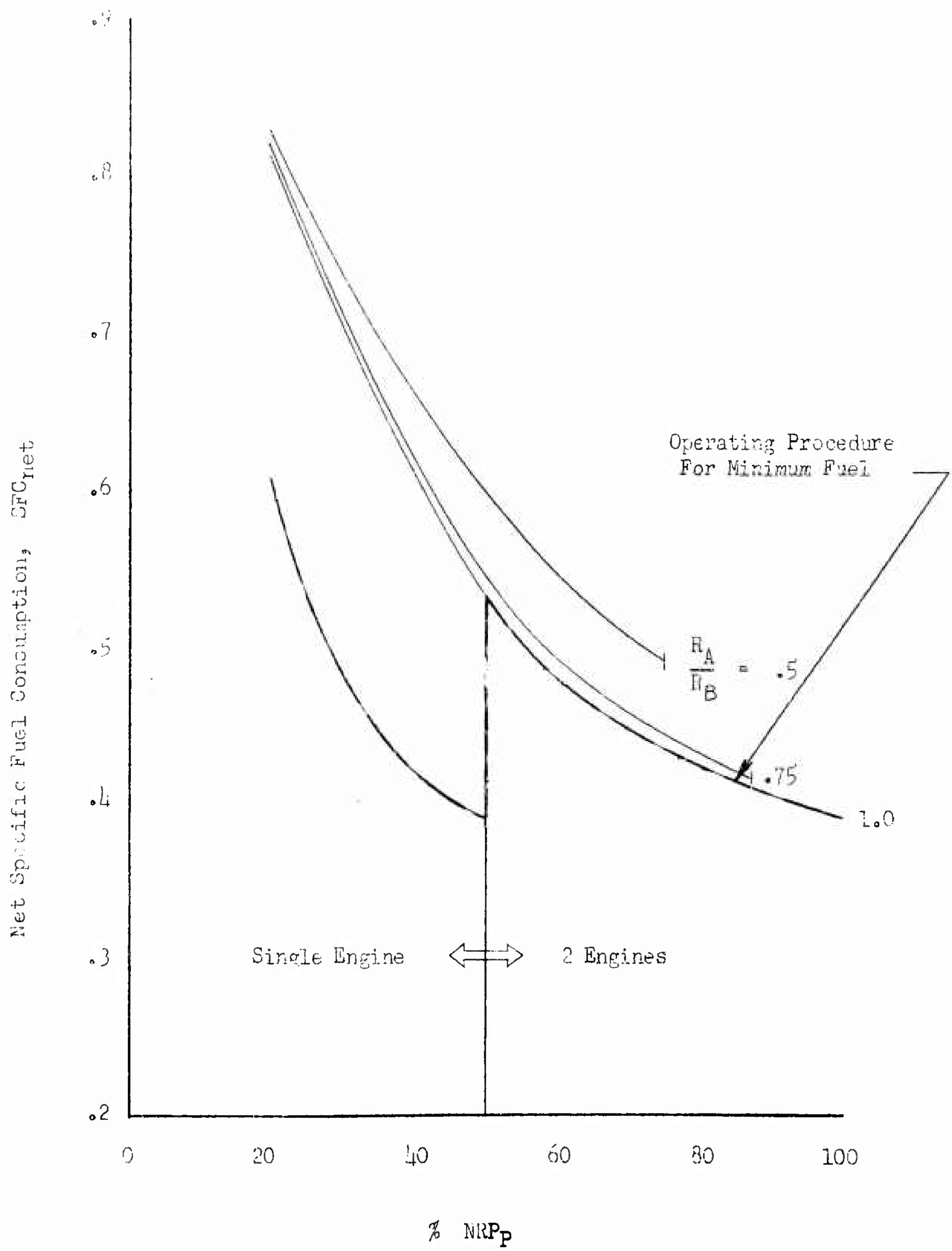
$$SPC_{NET} = SFC_A\, R_A + SFC_B\, R_B \qquad (4)$$

$$\frac{R_A}{R_B} = \frac{SHP_A}{SHP_B} = \frac{\%\ NRP_A}{\%\ NRP_B} \qquad (5)$$

Using the specific fuel consumption characteristics of Figure 2, the SFC_{NET} is plotted against % NRP_P for various R_A/R_B in Figure 11. It is seen that the operating procedure for minimum fuel occurs when both engines are operated at the same % NRP. Below 50% NRP_P the procedure for minimum fuel consumption is to shut down one engine completely, thereby operating the remaining engine at a high % NRP and consequently lower specific fuel consumption.

C O N F I D E N T I A L

Figure 1...



2.6.2 % NRP_8 - 75-100%

For the total required power falling in the range of 75 to 100% of available power, there are two possible operating procedures:

1. Maintain all 8 engines at the same % NRP.
2. Maintain one pair of nacelles, say, the outboard at 100%NRP while varying the inboard as required.

To evaluate these two possibilities, the following equations are developed.

Let subscript, i, denote inboard,
subscript, o, denote outboard,
subscript, 8, denote 8 engine or total.

$$\frac{\text{TOTAL FUEL}}{\text{HR}} = SFC_i\ SHP_i + SFC_o\ SHP_o$$

but $$SHP = \frac{THP}{\eta}\text{; therefore}$$

$$\frac{\text{TOTAL FUEL}}{\text{HR}} = SFC\ \frac{THP_i}{\eta_i} + SFC\ \frac{THP_o}{\eta_o} \tag{6}$$

$$\text{Let } R_i = \frac{\dfrac{THP_i}{\eta_i}}{\dfrac{THP_8}{\eta_8}}, \quad R_o = \frac{\dfrac{THP_o}{\eta_o}}{\dfrac{THP_8}{\eta_8}} \quad \text{Then,}$$

$$\frac{R_i}{R_o} = \frac{\dfrac{THP_i}{\eta_i}}{\dfrac{THP_o}{\eta_o}} \tag{7}$$

$$THP_i + THP_o = THP_8 \tag{8}$$

Combining (7) and (8)

$$THP_o = \frac{THP_8\ \dfrac{\eta_o}{\eta_i}}{\dfrac{R_i}{R_o} + \dfrac{\eta_o}{\eta_i}}, \quad THP_i = \frac{THP_8\ \dfrac{R_i}{R_o}}{\dfrac{R_i}{R_o} + \dfrac{\eta_o}{\eta_i}}$$

2.6.2 <u>% NRP8 – 75-100% (Continued)</u>

and substituting these in (6)

$$\frac{\text{FUEL}}{\text{THP - HR}} = \frac{SFC_i}{\eta_i} \frac{\frac{R_i}{R_o}}{\left(\frac{R_i}{R_o} + \frac{\eta_o}{\eta_i}\right)} + \frac{SFC_o}{\eta_o} \frac{\frac{\eta_o}{\eta_i}}{\left(\frac{R_i}{R_o} + \frac{\eta_o}{\eta_i}\right)} \qquad (9)$$

From Equation (7) and (8)

$$\frac{\eta_i}{\eta_8} R_i + \frac{\eta_o}{\eta_8} R_o = 1 \qquad (10)$$

From Equation (7)

$$\frac{R_i}{R_o} = \frac{\%\ NRP_{ei}}{\%\ NRP_{eo}} \qquad (11)$$

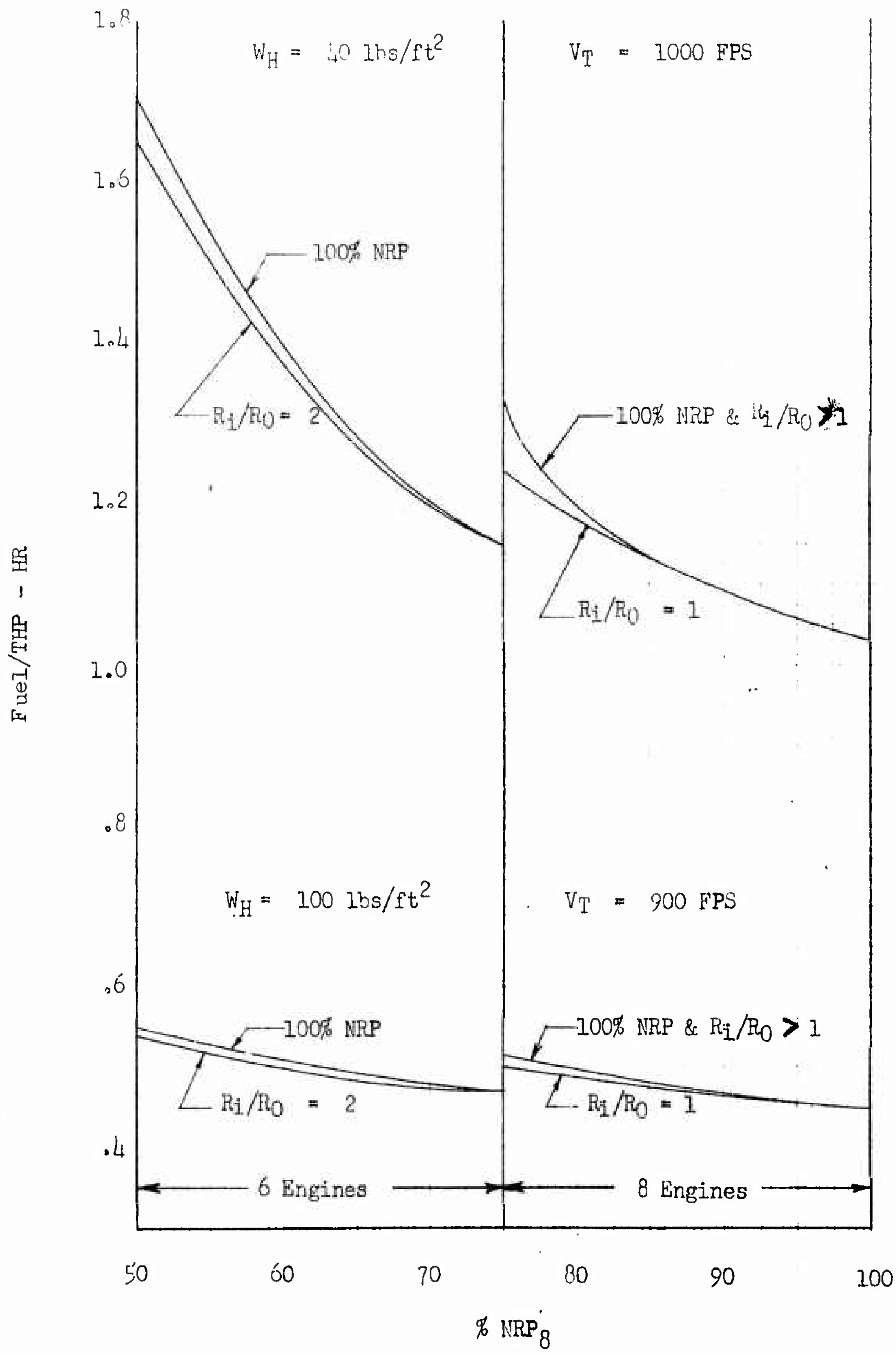
Also,

$$\frac{1}{2} \frac{\eta_i}{\eta_8} \%\ NRP_{ei} + \frac{1}{2} \frac{\eta_o}{\eta_8} \%\ NRP_{eo} = \%\ NRP_8 \qquad (12)$$

Using the above relations the two possible operating procedures evaluated on two representative aircraft (Figure 12). It is seen that the minimum fuel is required when both inboard and outboard nacelles are maintained at the <u>same</u> power (Alternate 1).

C O N F I D E N T I A L

Figure 12.



CONFIDENTIAL

2.6.3 <u>% NRP8 - 50 to 75%</u>

In this range the following engine operating alternatives exist:

1. 8 engines operating at same % NRP.
2. 6 engine operation as follows: (Assume 2 outboard engines shut down.)

   a. All 6 engines at same % NRP, that is, $R_i/R_o = 2$

   b. Maintain single outboard engines at 100% and vary inboard as required.

Equations for 6 engine operation are obtained in similar manner to 2.6.2.

$$\frac{1}{2}\frac{\eta_i}{\eta_8} \% \, NRP_{ei} + \frac{1}{4}\frac{\eta_o}{\eta_8} \% \, NRP_{eo} = \% \, NRP_8 \qquad (13)$$

$$\frac{R_i}{R_o} = 2\,\frac{\% \, NRP_{ei}}{\% \, NRP_{eo}} \qquad (14)$$

Evaluation of the above operating procedures is provided by the same two representative aircraft (Figure 12). Minimum fuel requirements are obtained in this range by operating six engines at the same power (Alternative 2a).

2.6.4 <u>% NRP 50% or Less</u>

From the preceding sections it has been found desirable to shut down engines whenever possible and to operate the remaining ones at the same percent of power. In view of this, then, the possibility of operating 6 or 8 engines in this range may be eliminated. The two remaining alternatives are:

1. One pair of propellers feathered, 4 engines in 2 nacelles operating.

2. 4 engines in 4 nacelles operating.

CONFIDENTIAL

CONFIDENTIAL

2.6.4 % NRP 50% or Less (Continued)

The apparent advantage of operating half of the propellers at higher power and, hence, higher efficiency must be weighed against the increased drag of the feathered propellers.

From Reference 6 for a three bladed propeller,

$$D = \frac{\rho v^2 Dp^2 T_C}{3}$$

and for a six bladed propeller,

$$\Delta THP_r = \frac{2Dv}{550} \text{ , or}$$

$$\Delta THP_r = \frac{2 \rho v^3 Dp^2 T_C}{3(550)}$$

For evaluating THP_r the following conditions are assumed:

1. Turbine torque is zero (assumes the use of shutters or vanes); therefore $Q_C = 0$, $\beta_{.75R} = 85$, and $T_C = .008$.
2. Comparison is made at sea level standard conditions.
3. Comparison is made at minimum mission speed of 260 knots.

The expression for ΔTHP_r is, then, $\Delta THP_r = 1.96\ Dp^2$

The increase in available THP for the same SHP that would result from supplying the required power by one propeller at higher efficiency rather than two at reduced efficiency is listed in the table below for representative aircraft.

Corresponding THP_r due to the feathered propeller is also tabulated for comparison.

CONFIDENTIAL

2.6.4 % NRP 50% or Less (Continued)

W_H	W_G	V_T	D_P	ΔTHP_a	ΔTHP_r
40	40000	800	20.36	1300	810
	80000	to 1000	28.80	2200	1620
100	40000		12.86	300	320
	80000		18.20	400	645

From the above table there appears to be little advantage in feathering propellers. Furthermore, the selection of the optimum is facilitated and not affected by considering all propellers in operation.

2.6.5 Fuel Consumption

This section provides the method used to calculate fuel consumption with engines operating according to the schedules for minimum fuel of the preceding sections.

$$\frac{\text{TOTAL FUEL}}{\text{HR}} = SFC_i \frac{THP_i}{\eta_i} + SFC_o \frac{THP_o}{\eta_o} \tag{15}$$

2.6.5.1 8 Engine Operation

For a given flight condition the total required THP is evenly divided between inboard and outboard nacelles, thus,

$$\text{TOTAL } THP_r = THP_i + THP_o$$

$$\eta_i = \eta_o \text{ , and}$$

$$SFC_i = SFC_o \text{ ; therefore}$$

$$\frac{\text{TOTAL FUEL}}{\text{HR}} = SFC \frac{THP_r}{\eta}$$

2.6.5.1 8 Engine Operation (Continued)

The calculation procedure is, then

a. Read THP_r at the given flight condition (Figure 3 or 4).

b. Read percent of normal rated power of propeller shaft, % NRPp (Figure 7 or 9).

c. Read η at %NRPp (Figure 8 or 10).

d. % NRP_e = % NRPp for 8 engine operation. Read SFC at NRP_e (Figure 2.).

2.6.5.2 6 Engine Operation

The total required THP is not evenly divided between inboard and outboard nacelles; however it is convenient to determine a relationship for total fuel/hr which is independent of individual nacelle operation, hence,

$$\frac{\text{TOTAL FUEL}}{\text{HR}} = \text{SFC}\ \frac{THP_r}{\eta_8} \quad \text{where}$$

THP_r = Total required thrust horsepower

η_8 = propeller efficiency for 8 engine operation and is read at the percent of 8 engine normal rated power. This relation is based on the assumption that

$$\frac{THP_r}{\eta_8} = \frac{THP_i}{\eta_i} + \frac{THP_o}{\eta_o}$$

Although the propellers are operating at different efficiencies, the compensating variation of THP_i and THP_o is sufficient to make the assumption reasonably valid for the matrix.

SFC = effective specific fuel consumption and is read at

$$\frac{\%\ NRP_8}{.75}$$

with reference to equation (13) with all 6 engines at the same % NRP.

CONFIDENTIAL

2.6.5.2 6 Engine Operation (Continued)

$$\% \; NRP_e = \frac{\% \; NRP_8}{\frac{1}{2}\frac{\eta_i}{\eta_8} + \frac{1}{4}\frac{\eta_o}{\eta_8}}$$

The denominator,

$$\frac{1}{2}\frac{\eta_i}{\eta_8} + \frac{1}{4}\frac{\eta_o}{\eta_8},$$

when checked over the matrix is found to remain nearly constant at .75.

Fuel/hr is calculated as follows:

a. Read THP_r at the given flight condition (Figure 3 or 4).

b. Read percent of 8 engine normal rated power, % NRP (Figure 7 or 9).

c. Read η_8 at % NRP_8 (Figure 8 or 10).

d. Read SFC at $\frac{\% \; NRP_8}{.75}$ (Figure 2.).

2.6.5.3 4 Engine Operation

The total required THP is evenly divided between inboard and outboard nacelles, thus,

$$\text{TOTAL } THP_r = THP_i + THP_o$$

$$\eta_i = \eta_o \quad \text{and}$$

$$SFC_i = SFC_o \text{ ; therefore}$$

$$\frac{\text{TOTAL FUEL}}{\text{HR}} = SFC \frac{THP_r}{\eta}$$

CONFIDENTIAL

CONFIDENTIAL

2.6.5.3 4 Engine Operation (Continued)

Calculate total fuel/hr as follows:

a. Read THP_r at the given flight condition (Figure 3 or 4).

b. Read percent of normal rated power of propeller shaft, % NRP_P (Figure 7 or 9).

c. Read η at % NRP_P (Figure 8 or 10).

d. % NRP_e = $\frac{\% NRP_P}{.5}$. Read SFC at % NRP_e (Figure 2).

2.6.6 Engine Operation

The following table summarizes engine operation.

Sea Level Operation

% 8 ENGINE NRP	ENGINE OPERATION	% NRP/ENGINE	% NRP AT WHICH TO READ SFC
100 - 75	Engines can not be operated in this range due to gear box derating.		
75 - 62.5	8 Engines at same % NRP	75 to 62.5	Same as 8 engine % NRP
62.5 - 56.2	6 Engine Operation	4 engines @ 75% 2 engines @ 100 to 75%	$\frac{\% NRP_8}{.75}$
56.2 to 50	6 engines at same % NRP	6 engines - 75 to 67%	$\frac{\% NRP_8}{.75}$
50 or less	4 engines at same % NRP All propellers operating	4 engines - 100% or less	$\frac{\% NRP_8}{.5}$

CONFIDENTIAL

CONFIDENTIAL

2.6.6 Engine Operation (Continued)

25,000' Operation

% 8 ENGINE NRP	ENGINE OPERATION	% NRP/ENGINE	% NRP AT WHICH TO READ SFC
100 - 75	8 engines at same % NRP	100 - 75	Same as 8 engine % NRP
75 - 50	6 engines at same % NRP	75 - 50	$\frac{8 \text{ Engine \% NRP}}{.75}$
50 or less	4 engines at same % NRP All propellers operating	50 or less	$\frac{8 \text{ Engine \% NRP}}{.5}$

2.7 Rate of Climb

Rate of climb is obtained from the expression:

$$\frac{R}{C} = \frac{33000}{W_G} (THP_a - THP_r) \qquad (16)$$

Figure (13) is a graphical solution of equation (16) for rapid calculation of rate of climb. The maximum rate of climb is obtained at the velocity where the difference between THP_a and THP_r is greatest.

2.8 Rate of Descent

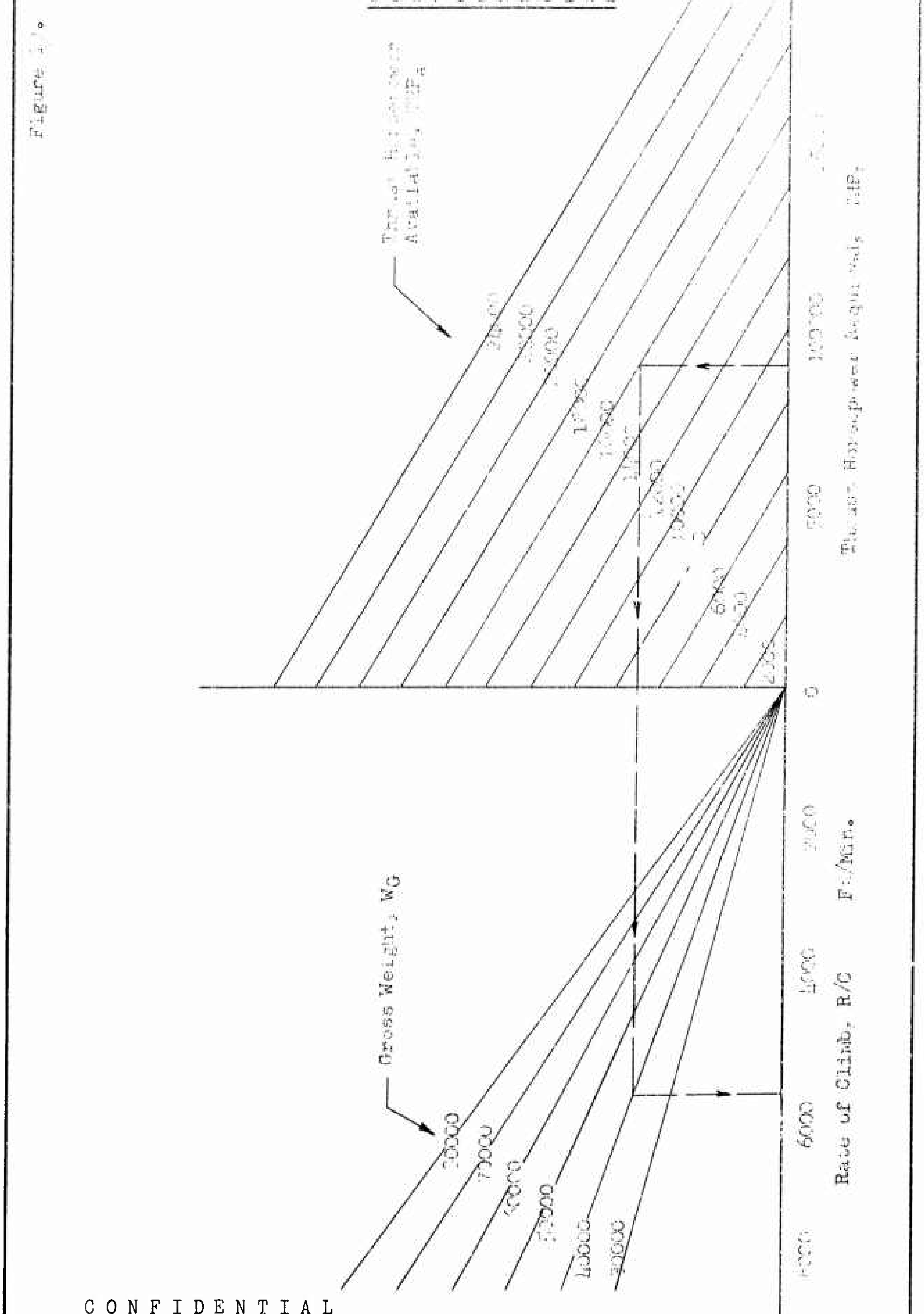
Equation (17) defines airplane rate of descent with power on.

$$\frac{R}{D} = \frac{33000}{W_G} (THP_r - THP_a) \qquad (17)$$

CONFIDENTIAL

PREPARED	NAME	DATE	HILLER HELICOPTERS	PAGE
CHECKED			TITLE	MODEL
APPROVED				REPORT NO

CONFIDENTIAL



CONFIDENTIAL

CONFIDENTIAL

2.9 Installed Horsepower

The sea level installed horsepower can be readily determined if the ratio

$$\frac{\text{Sea Level Propeller Thrust}}{\text{Hover ceiling altitude propeller thrust + engine jet thrust}} = \frac{\text{Sea Level Propeller Thrust}}{\text{Gross Weight}}$$

is known. This ratio is dependent upon propeller and engine characteristics. For the dual rotating propellers, gas turbine power plants, 6000', 95°F hover ceiling, and matrix under consideration, this ratio was found to remain essentially constant at 1.3.

3.0 SPECIFIED AIRCRAFT PERFORMANCE AND MISSION REQUIREMENTS

The specified aircraft performance and mission requirements are listed below.

3.1 Required payload is 5000 lbs. outbound and 4000 lbs. return.

3.2 Hover ceiling 6000', 95°F.

3.3 Cruise speed 300 MPH minimum (260 knots).

3.4 Mission per Figure 14.

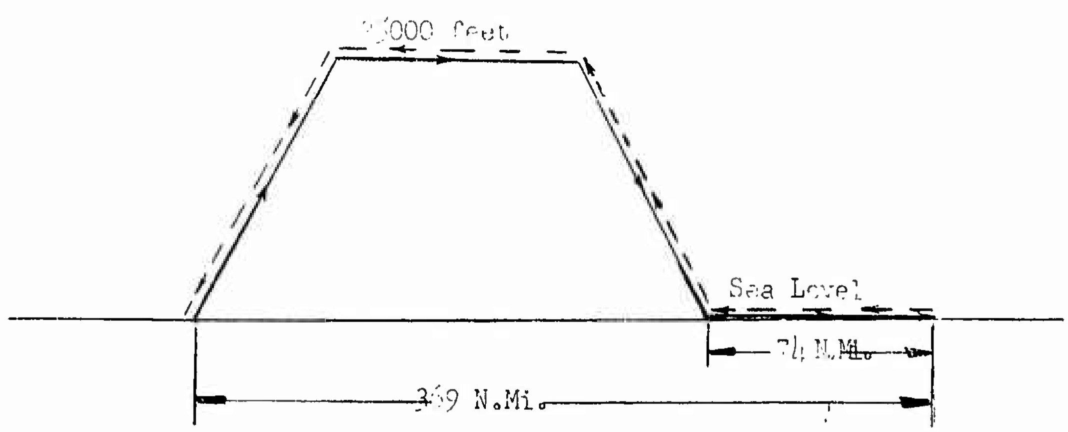


Figure 14.

CONFIDENTIAL

CONFIDENTIAL

3.5 Total Mission Fuel

To determine the total fuel required for the mission, and hence, the "RF", the mission is broken down into component parts. Fuel required for each part is determined, the summation of these providing the total mission fuel.

3.5.1 Starting Fuel

A starting and maneuvering time of 2 minutes per flight leg is assumed, giving a total of 4 minutes. During this time 8 engines are assumed to be operating at 75% NRP. It is further assumed that the operation is at sea level.

$$F_S = SFC\,(t)(SHP)$$

$$SFC = .43$$

$$t = \frac{4}{60}$$

SHP = 75% of total installed power

$$F_S = .0287\ SHP$$

3.5.2 Reserve Fuel

Reserve fuel is assumed to be 10% of total fuel.

3.5.3 Climb Fuel

The following assumptions are made regarding climb fuel.

a. A climb to 25000 feet in the shortest time is assumed most economical.

b. Rate of climb at sea level is calculated with 8 engines operating at 75% NRP due to gear box derating.

c. Rate of climb at 25000' is calculated with 8 engines operating at 100% NRP (100% NRP at 25000 feet is equal to 60% sea level NRP, Reference 3).

d. A linear variation of SHP, SFC, V_C, and R/C between sea level and 25000 ft. is assumed.

CONFIDENTIAL

CONFIDENTIAL

3.5.3 <u>Climb Fuel (Continued)</u>

Fuel to climb is then calculated as follows

$$F_C = R_C \frac{SFC}{V_C} SHP \quad \text{where}$$

$$R_C = \frac{V_C \Delta H}{60 \frac{R}{C}} \quad \text{and}$$

V_C = average climb velocity between S.L. and 25000 feet for maximum rate of climb.

R_C = Range credit during climb.

ΔH = 25000 feet.

$\frac{R}{C}$ = Average rate of climb between S.L. and 25000' (Reference to Section 2.7)

SHP = Average SHP between S.L. and 25000'.

SFC = Average SFC between S.L. and 25000'.

3.5.4 <u>Descent Fuel</u>

Calculation of descent fuel is based on the following assumptions.

a. Rate of descent, R/D, is constant at 2500 ft/min.

b. Descent velocity, V_D, = 300 knots.

c. Most economical engine operation per section 2.6 is assumed.

d. A linear variation of SHP, and SFC between 25000' and S.L. is assumed.

$$F_D = R_D \frac{SFC}{V_D} SHP \quad \text{where}$$

$$R_D = V_D \frac{\Delta H}{60 \frac{R}{D}}$$

V_D = 300 knots

ΔH = 25000'

$\frac{R}{D}$ = 2500 ft/min.

CONFIDENTIAL

CONFIDENTIAL

3.5.3 Climb Fuel (Continued)

Fuel required for the climb is calculated as follows

$$F_C = R_C \frac{SFC}{V_C} SHP, \text{ where}$$

$$R_C = \frac{V_C \, \Delta H}{60 \, \frac{R}{C}} \quad \text{and}$$

V_C = average climb velocity between S.L. and 25000 feet for maximum rate of climb.

R_C = Range credit during climb.

ΔH = 25000 feet.

$\frac{R}{C}$ = Average rate of climb between S.L. and 25000' (Reference to Section 2.7)

SHP = Average SHP between S.L. and 25000'.

SFC = Average SFC between S.L. and 25000'.

3.5.4 Descent Fuel

Calculation of descent fuel is based on the following assumptions.

a. Rate of descent, R/D, is constant at 2500 ft/min.

b. Descent velocity, V_D, = 300 knots.

c. Most economical engine operation per section 2.6 is assumed.

d. A linear variation of SHP, and SFC between 25000' and S.L. is assumed.

$$F_D = R_D \frac{SFC}{V_D} SHP \quad \text{where}$$

$$R_D = V_D \frac{\Delta H}{60 \frac{R}{D}}$$

V_D = 300 knots

ΔH = 25000'

$\frac{R}{D}$ = 2500 ft/min.

CONFIDENTIAL

CONFIDENTIAL

3.5.4 Descent Fuel (Continued)

R_D = [illegible] N.Mi

SFC = Average between 25000' and S.L.

SHP = Average between 25000' and S.L. May be obtained from equation (17).

3.5.5 Cruising Fuel - 25,000'

Fuel for 25000' cruise $= \frac{R}{V}\left(\frac{\text{Fuel}}{\text{HR}}\right)$ where

$\left(\frac{\text{Fuel}}{\text{HR}}\right)$ is obtained according to Section 2.6.5.

V is cruise velocity. It is selected for minimum fuel/mile, but according to mission requirements, in no case less than 260 knots.

$R = 245 - R_C$ (N.Mi)

3.5.6 Cruising Fuel - Sea Level

Fuel for sea level cruise $= \frac{R}{V}\left(\frac{\text{Fuel}}{\text{HR}}\right)$ where

$\left(\frac{\text{Fuel}}{\text{HR}}\right)$ is obtained according to Section 2.6.5

V is cruise velocity for minimum fuel/mile, and equal to or greater than 260 knots.

R = 74 N.Mi

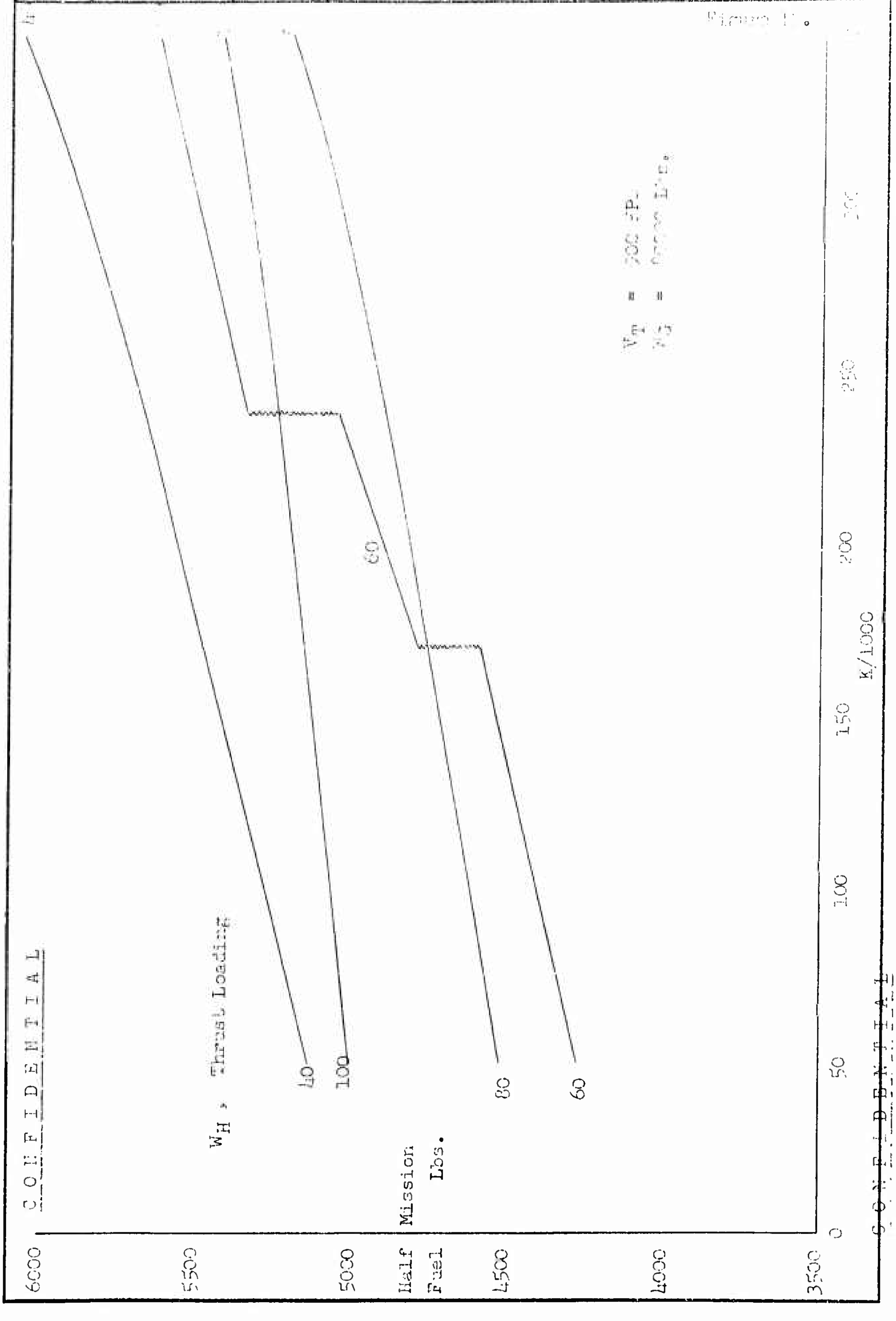
3.5.7 Return Half of Mission

The return half of mission is identical to the outbound half except for the gross weight which is reduced by the amount of the fuel used for the first half and 4000 lbs. payload. The predominant effect of the lower gross weight is in the reduction of induced drag of which the term "K" (Section 2.4) is a function.

For the purpose of determining outbound fuel requirements for the matrix range of wing loadings and aspect ratio a plot is made of fuel versus "K". Figure (15) is such a curve presented for purposes of illustration. From this curve the half mission fuel can be read for my combination of W/S and AR. Also, from this same curve the return fuel can be read at the new value of "K" for the return half.

CONFIDENTIAL

PREPARED	NAME	DATE	HILLER HELICOPTERS	PAGE
CHECKED			TITLE	MODEL
APPROVED				REPORT NO



60-028

CONFIDENTIAL

4.0 MATRIX

The range of parameters considered is outlined below (Figure 16).

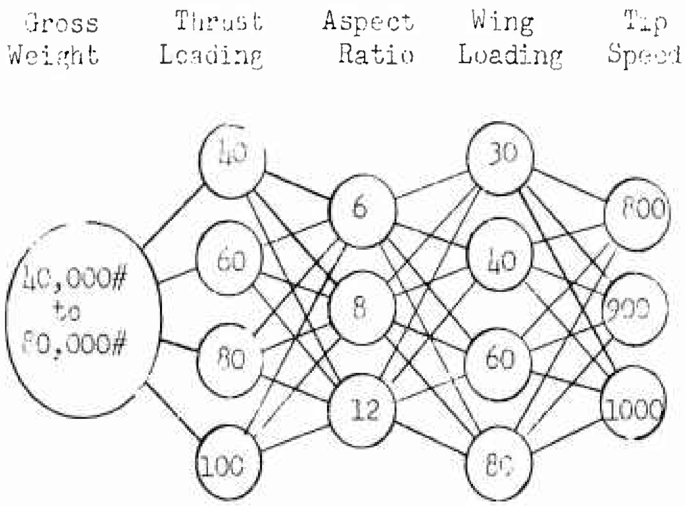


Figure 16.

5.0 MODEL 1048-A, OPTIMUM AIRCRAFT

Physical characteristics and performance of the optimum aircraft are tabulated below.

Gross Weight	71,250 lbs.
Fuel Weight	11,200 lbs.
Empty Weight	51,290 lbs.
Installed Horsepower	8 engines @ 3750 NRP
Disk Loading	65.4 lbs/sq.ft.
Tip Speed	900 ft/sec
Propeller Diameter	18.6 ft.
No. Blades	6
Activity Factor	135
Wing Loading	90 lbs/sq.ft.
Aspect Ratio	6.5
Wing Area	792 sq.ft.
Span	71.8 ft.

CONFIDENTIAL

CONFIDENTIAL

5.0 MODEL 1047-A, OPTIMUM AIRCRAFT (Continued)

Stall Speed, Sea Level Standard, Power Off	125 kts.
Cruise Speed, Sea Level	260 kts.
Cruise Speed, 25000'	300 kts.
Maximum Speed, Sea Level (75%NRP)	350 kts.
Maximum Speed, 25000' (100%NRP)	410 kts.
Vertical Rate of Climb, 6000', 95°F, Maximum Power	700 FPM
Vertical Rate of Climb, Sea Level, 75% NRP	3700 FPM
Rate of Climb, Sea Level, 75% NRP	6300 FPM
Rate of Climb, 25000', 100% NRP	4100 FPM
Hover Ceiling, 95° F, NRP	6000 ft.
Hover Ceiling, Standard Atmosphere, Maximum Power	14700 ft.
Service Ceiling, NRP, Gross Weight	40000 ft.
Static Thrust, Sea Level, 75% NRP	85000 lbs.
Static Thrust, Sea Level, 100% NRP (Over Gear Box Rating)	102000 lbs.
Static Thrust, 6000', 95°F, Maximum Power, 2 Engines Out	62800 lbs.
Ferry Range at 20% Overload, 25000' Cruise Altitude, 10% Reserve	2800 N.Mi.

5.1 Power Required

Figure 17 is a plot of shaft horsepower required and available for sea level standard conditions. Power required for the transition region was calculated according to the method provided by Reference (7).

5.2 Jet Thrust

Figure 18 shows the effect of turbine jet thrust on cruising fuel economy. As originally assumed, the difference in fuel consumption is negligible.

5.3 Best Cruise Speed

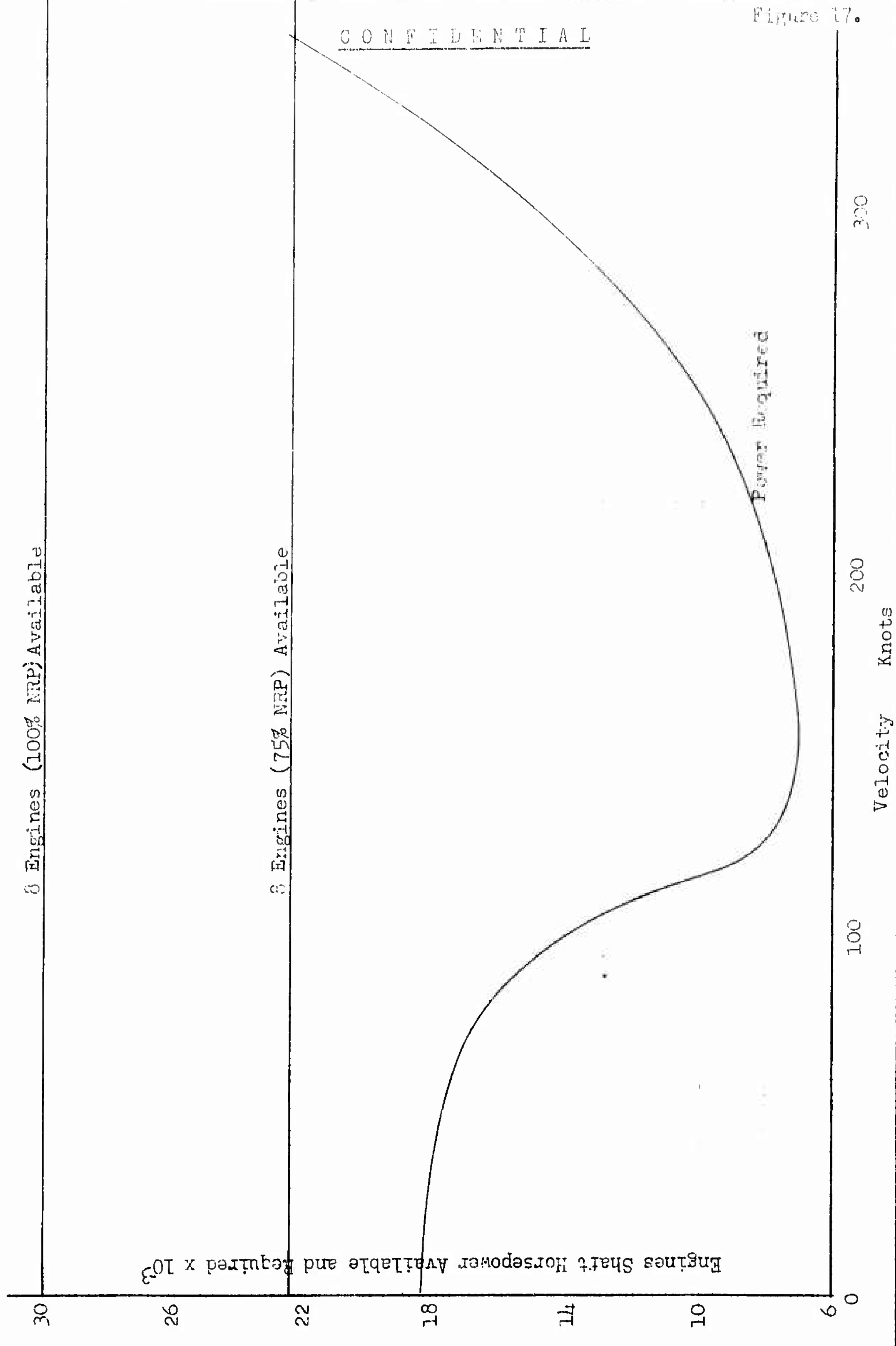
Figure 18 also shows the velocity for minimum fuel consumption to be 260 knots at sea level and 300 knots at 25,000'.

CONFIDENTIAL

PREPARED	NAME	DATE	HILLER HELICOPTERS	PAGE
CHECKED			TITLE Aerodynamic Analysis Report For Transport Propellerplane Study Contract Nonr 1597 (?)	MODEL
APPROVED				REPORT NO.

Figure 17.

CONFIDENTIAL



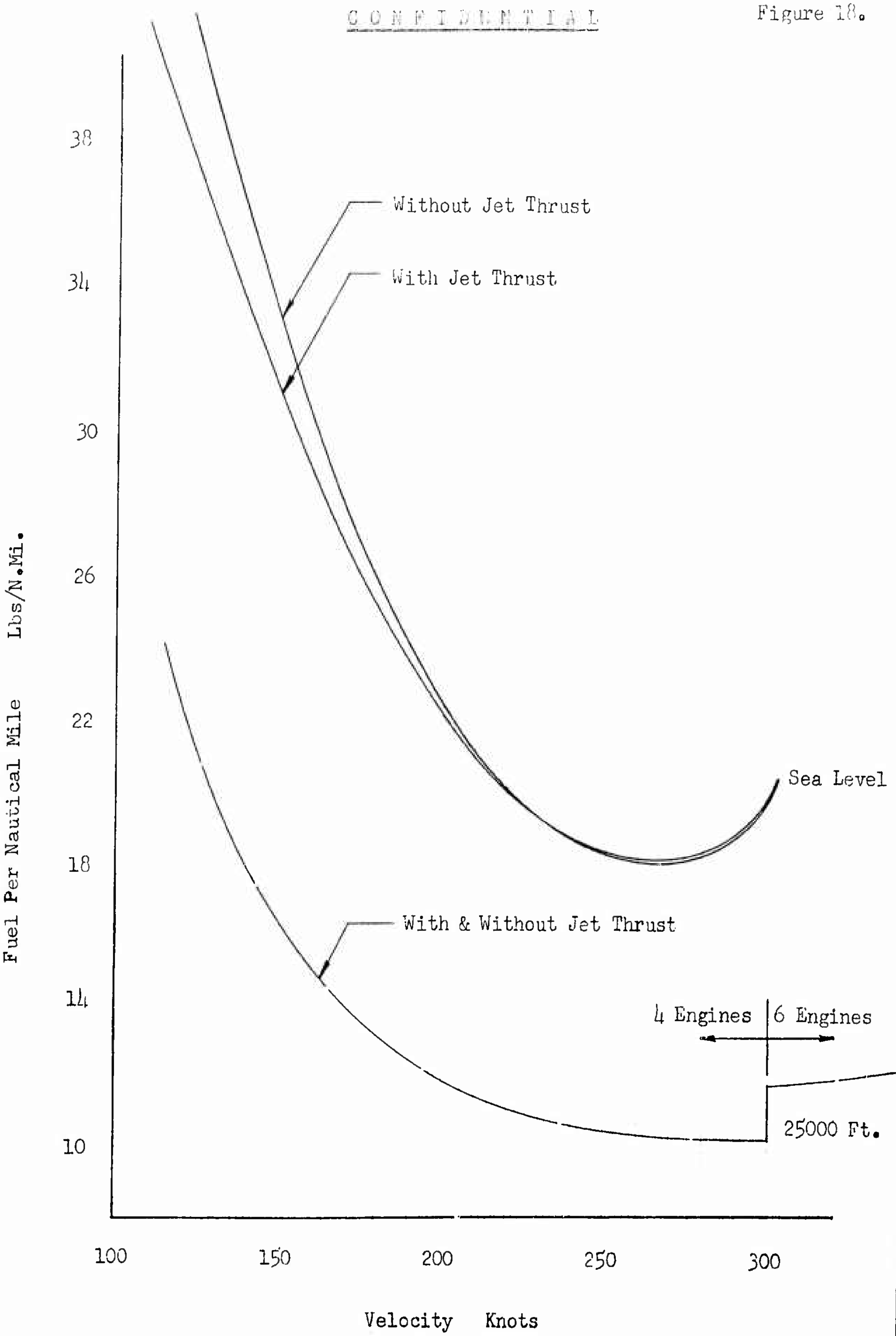
CONFIDENTIAL

60-028

PREPARED	NAME: N. Young	DATE	HILLER HELICOPTERS	PAGE
CHECKED			TITLE Aerodynamic Analysis Report For Transport Propelloplane Study Contract Nonr 1697 (00)	MODEL 1048
APPROVED				REPORT NO. 114.7

CONFIDENTIAL

Figure 18.



CONFIDENTIAL

60-028

CONFIDENTIAL

5.4 <u>Take-Off Distance</u>

Distances required for running take-off to clear a 50 ft. obstacle are provided by Figure 19. The methods of References 8 and 4 were employed and assume a level, smooth concrete runway, sea level standard conditions.

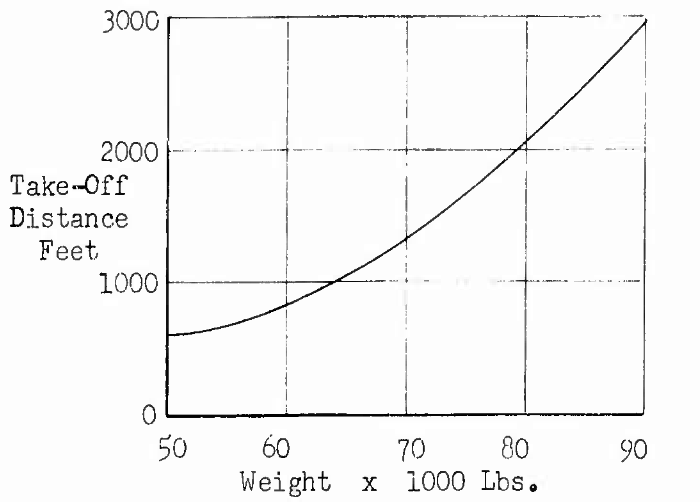


Figure 19.

5.5 <u>Off-Design Operation</u>

Figure 20 shows the range-payload capabilities of this aircraft when fuel and payload are interchanged. Also, as shown, the capabilities are further enhanced when an overloaded running take-off is permitted from home base with a vertical landing and take-off at the remote base.

6.0 <u>MODEL 1048-B</u>

Contract Nonr 1657 (00) was extended an additional period of time in order to establish an aircraft capable of meeting the specified mission and hover ceiling using engines, propellers, and other components available for production in the year 1960.

Two more requirements of the mission were added, namely:

1. Fuel required shall be computed as 2.2 times the fuel required for the first half of the mission. This method of computation is essentially the same as the method used for the main study except that the small reduction in fuel required for the second half due to reduced gross weight is not accounted for.

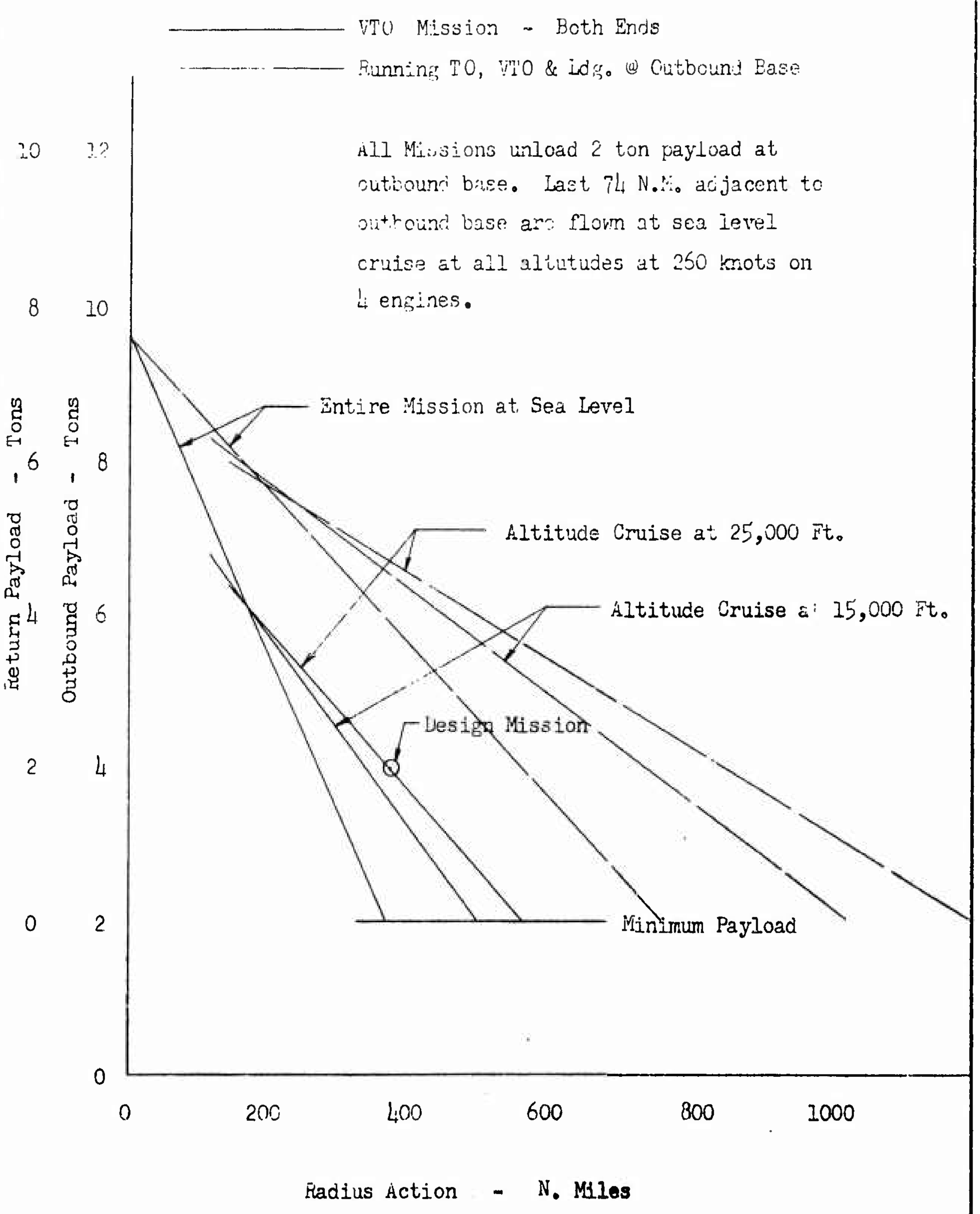
CONFIDENTIAL

Figure 20.

CONFIDENTIAL

PAYLOAD - RANGE

"OPTIMUM" PROPELLOPLANE



?.0 MODEL 1048-B (Continued)

2. The specific fuel consumption shall be increased 5% over the manufacturer's guaranteed value.

Mission and hover ceiling requirements are met by the use of water-alcohol injection for the initial take-off. The aircraft reaches design gross weight of 93000 lbs. for the first landing at the remote base.

The following tabulation lists the physical characteristics and performance.

Take-Off Gross Weight	=	101,000 lbs.
Design Gross Weight	=	93,000 lbs.
Fuel Weight	=	18,500 lbs.
Disk Loading	=	64.05 lb/ft^2
Wing Loading	=	90 lb/ft^2
Propeller Diameter	=	21.5 ft
No. Blades	=	6 (Dual)
Activity Factor	=	135/Blade
Tip Speed	=	900 FPS
Aspect Ratio	=	6.5
Wing Area	=	1032 ft^2
Span	=	81.9 ft.

Installed Horsepower: 8 Allison 550-B1 Engines @ 4590 NRP

Water-Alcohol	=	1450 lbs.
Stall Speed, Sea Level, Standard-Power Off	=	125 knots
Cruise Speed, Sea Level	=	270 knots
Cruise Speed, 25000 feet	=	300 knots
Maximum Speed, Sea Level (75% NRP)	=	365 knots
Maximum Speed, 25000 feet	=	465 knots
Rate of Climb, Sea Level, 75% NRP	=	6860 FPM
Rate of Climb, 25000 feet, 100% NRP	=	5800 FPM

Hover @ 6000 ft., 95°F, Take-Off Gross Weight requires 76% maximum available power + water/alcohol injection.

Hover Ceiling, Standard Atmosphere, Maximum Power + Water/Alcohol Injection	=	18,650 ft.
Service Ceiling, NRP, W_G	=	49,200 ft.
Static Thrust, S.L., 75% NRP	=	106,300 lbs.
Static Thrust, S.L., 100% NRP	=	127,000 lbs.

CONFIDENTIAL

6.0 MODEL 1048-B (Continued)

Static Thrust, 6000 ft., 95°F, Maximum Power, 2 Engines Out	=	81,950 lbs.
With Water/Alcohol Injection Added	=	95,000 lbs.
Vertical R/C, 6000 ft., 95°F, Maximum Power, + Water/Alcohol Injection, $W_{T.O.}$	=	3,950 FPM
Vertical R/C, S.L., 75% NRP, Take-Off W_G	=	1,520 FPM
Ferry Range @ 20% Overload, 25000 ft Cruise Altitude, 10% Reserve	=	2,050 N.Mi.

7.0 MODEL 1048-D

A brief investigation was made as to the type of mission that could be made with Model 1048-A using presently available engines and propellers.

As specified, 20 percent of the mission is flown at sea level. With a 6000 lb. payload a mission radius of 270 N.Mi. can be flown. Hot Day (95°F) hover ceiling of 6000 feet is met with the use of water/alcohol injection for the initial take-off and for the first landing at the remote base.

On the other hand, the specified mission radius of 369 N.Mi. with 8000 lbs. payload can be met if the hover ceiling is reduced to 6200 feet standard altitude.

The following tabulation lists the characteristics of Model 1048-D.

Take-Off Gross Weight	=	83,600 lbs.
Payload	=	6,000 lbs.
Fuel	=	13,000 lbs.
Water/Alcohol	=	2,900 lbs.
Propeller Diameter	=	19.08 ft.
No. Blades	=	8 (Dual)
Activity Factor	=	135/Blade
Tip Speed	=	900 FPS
Engines - 8 Allison 501-D8 @ 3316/Engine, S.L., NRP.		
Weight @ First Landing	=	71250 lbs.
Hover Ceiling, . . . NRP, Standard, Take-Off Gross Weight (No Water/Alcohol Injection)	=	6200 ft.

CONFIDENTIAL

CONFIDENTIAL

7.0 MODEL 1048-D (Continued)

Hover Ceiling. . . . . Maximum Power (No Water-Alcohol Injection), Take-Off Gross Weight . . . . = 8800 ft.

Hover @ 6000 ft., 95°F, Take-Off Gross Weight requires 94% available Maximum Power + H_2O/Alcohol Injection.

Ferry Range @ 20% overload, 25000 ft. cruise Altitude, 10% Reserve . . . . = 12[illegible] N.Mi.

The methods used in computing the performance of models 1048-B and 1048-D are identical to those used for Model 1048-A except that the manufacturer's estimated engine performance, including the effects of jet thrust, were used in place of the generalized characteristics of Reference 3.

CONFIDENTIAL

CONFIDENTIAL

REFERENCES

1. "The ("R_F") Graphical Method of Parametric Analysis for the Development of Optimum Preliminary Design Aircraft", Hiller Helicopters Report No. 473.8.

2. "Derivation of Weight R_F Terms of Parametric Design Analysis for Propelloplane Transport Study Contract Nonr 1657 (00)", Hiller Helicopters Report No. 474.5.

3. "Generalized Shaft Turbine Engine Characteristics", Hiller Helicopters Report No. 630.5.

4. Wood, K.D., Technical Aerodynamics, Second Edition, McGraw-Hill Book Company, Incorporated, New York.

5. "Procedure and Data for Propeller Performance Analysis", Aeroproducts Division, General Motors Corporation, Dayton 1, Ohio, Report No. 190.

6. "Wind Tunnel Test of a Non-Rotating Propeller", Report No. C-2560, Curtiss-Wright Corporation, Propeller Division Caldwell, New Jersey.

7. "A Simplified Theoretical Investigation of a Wing-Propeller Combination through a Range of Angle-of-Attack from 0° to 90°, II - Partial Wake Deflection", Hiller Helicopters Report No. 461.31.

8. "The Ground Run of Aircraft in Landing and Take-Off in ICAO Units", Garbell Aeronautical Series No. 3, Garbell Research Foundation, San Francisco, California.

CONFIDENTIAL